Phosphorus Saturation Characteristics in Relation to Land-Use Practice for Soils in the Upper Eau Galle River Watershed, Wisconsin

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PURPOSE: The purpose of this demonstration was to determine relationships between phosphorus saturation characteristics and extractable phosphorus forms in soils from differing land-use practices in an agriculturally dominated watershed that drains into a U.S. Army Corps of Engineers impoundment. This information will be important for watershed modeling applications that use an index of soils to predict phosphorus loss during runoff.

BACKGROUND: Excessive phosphorus (P) runoff from agricultural watersheds is a leading cause of eutrophication of freshwater systems (Sharpley et al. 1994). Amendment of soils with fertilizers and manure is often based on crop nitrogen requirements, rather than P, to obtain optimal crop yield. This practice can result in the buildup of soil P to excessive levels, leading to exacerbated P runoff to receiving waters via solubilization and desorption during storms (Sharpley et al. 1994, Sharpley 1995, Fang et al. 2002). Both the soil sorption capacity for P (phosphorus sorption capacity = PSC; Sharpley 1995) and the degree of P saturation (DPS; Shoumans and Groenendijk 2000) in soils is typically correlated with runoff of soluble P and thus can provide an index of P runoff potential that may be used in watershed modeling applications and management scenarios (Sharpley 1995; Pote et al. 1996, 1999; Fang et al. 2002). However, more information is needed on the influence of land-use practices on the PSC and DPS of soils. For agriculturally managed soils, the PSC should be low, and the DPS higher, due to saturation of binding sites with excess P applied as fertilizer and manure. Conversely, the opposite pattern in PSC and DPS should be observed for unmanaged soils. Relations should also exist between the PSC and DPS of soils and extractable forms of P, particularly for water-extractable P, forms of adsorbed P, and crop-available P (i.e., Mehlich-3 P). These hypotheses were tested using soils collected in the Upper Eau Galle River Basin, Wisconsin, which drains into the USACE impoundment, Eau Galle Reservoir.

METHODS: Soils that were collected from areas with differing land-use practices (Table 1) in another study (see James et al. (2004)) were sieved through a 2-mm mesh screen, air-dried, and stored in a desiccator until analysis. The phosphorus sorption capacity (PSC) of soils was measured using a modification of the single-point isotherm (Nair et al. 1998). Homogenized soil was mixed with a phosphorus-augmented tap-water solution (100 mg P L$^{-1)}$ at a soil:solution ratio of 1:10. Tap water (Conductivity = 422 μS; Ca = 57 mg L^{-1}; Mg = 28 mg L^{-1}; K = 0.83 mg L^{-1}; pH = 7.8) was used to prepare this solution because it would simulate the ionic strength and pH of surface water in the surrounding watershed. Soil solution tubes were shaken in a darkened incubator at 20 °C

Table 1 Land-use Practices and Numbers of Soil Samples (n) Collected in Each Category	
Land-use	**N**
Alfalfa fields	13
Barnyard areas	9
Cornfields	21
CRP1	13
Forage pastures	9
Woodlots	16
[1] CRP = Conservation Reserve Program.	

for 24 hours. The equilibrated samples were then centrifuged at 500 g for 10 minutes and the supernatant was filtered through a 0.45-μ filter before determination of soluble reactive phosphorus

(SRP; APHA 1998). The PSC was calculated as the difference between the initial and final concentration of SRP divided by the dry mass of soil used in the assay. The degree of soil phosphorus saturation (DPS; Sharpley 1995) was calculated as:

$$DSP\ (\%) = \text{extractable soil P}/(PSC + NAP) * 100 \tag{1}$$

where NAP is the native adsorbed P present before the PSC assay. The extractable soil P and NAP were estimated as the sum of the loosely bound and iron-bound P. These fractions were determined using a sequential extraction with 1 M ammonium chloride followed by 0.11 M sodium bicarbonate-dithionate (Hieltjes and Lijklema 1980, Psenner and Puckso 1988). Other P fractions determined for soil characterization included Mehlich-3 crop-available P (Mehlich 1984) and water-extractable P (Southern Extension research Activity Information Exchange Group (SERA-IEG) 2000). Methods are described in James et al. (2004).

RESULTS AND DISCUSSION: Mean PSC and DSP varied as a function of land-use practice (Figure 1). The mean PSC was lowest for barnyard soils and the trend was barnyard soils
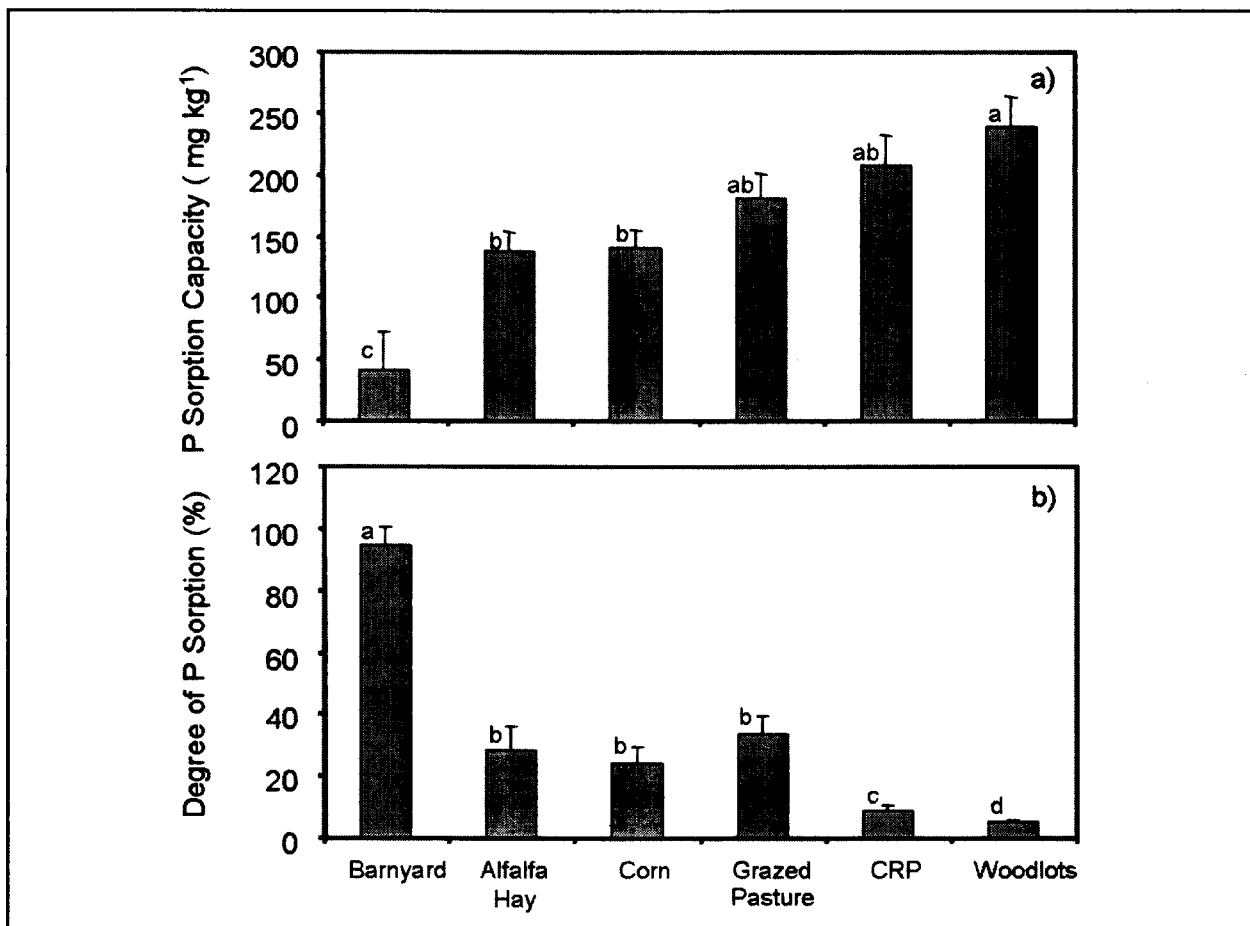

Figure 1. Mean (1 standard error = vertical line) phosphorus (P) sorption capacity (PSC) and the degree of P sorption (DSP) of soils from differing land uses in the upper Eau Galle River watershed. For each test (DSP or PSC), soils that are not significantly different from each other based on ANOVA (SAS 1994) are marked with the same letter (a, b, c, or d)

<< agriculturally-managed soils (i.e., alfalfa fields, cornfields, and pasture) < unmanaged soils (i.e., Conservation Reserve Program-CRP and woodlots). Conversely, the mean DSP was greatest for barnyard soils, lower for agriculturally managed soils, and lowest for unmanaged soils. Mean concentrations of extractable P fractions exhibited a similar pattern as a function of land-use practice (Figure 2). Barnyard soils exhibited the greatest mean concentrations of Mehlich-3 P, water extractable P, loosely bound P, and iron-bound P. Other agriculturally managed soils exhibited intermediate concentrations, and soils from CRP and woodlot land uses exhibited a trend of lower concentrations. Over all land uses, significant relationships existed between the PSC or DSP and extractable P fractions in the soil (Figure 3). PSC was negatively related to concentrations of Mehlich-3 P, loosely bound P, iron-bound P, and water-extractable P while the DSP was positively related to these extractable P forms. Significant correlations also existed between PSC, DPS, Mehlich-3 P, loosely bound P, iron-bound P, and water-extractable P (Table 2).
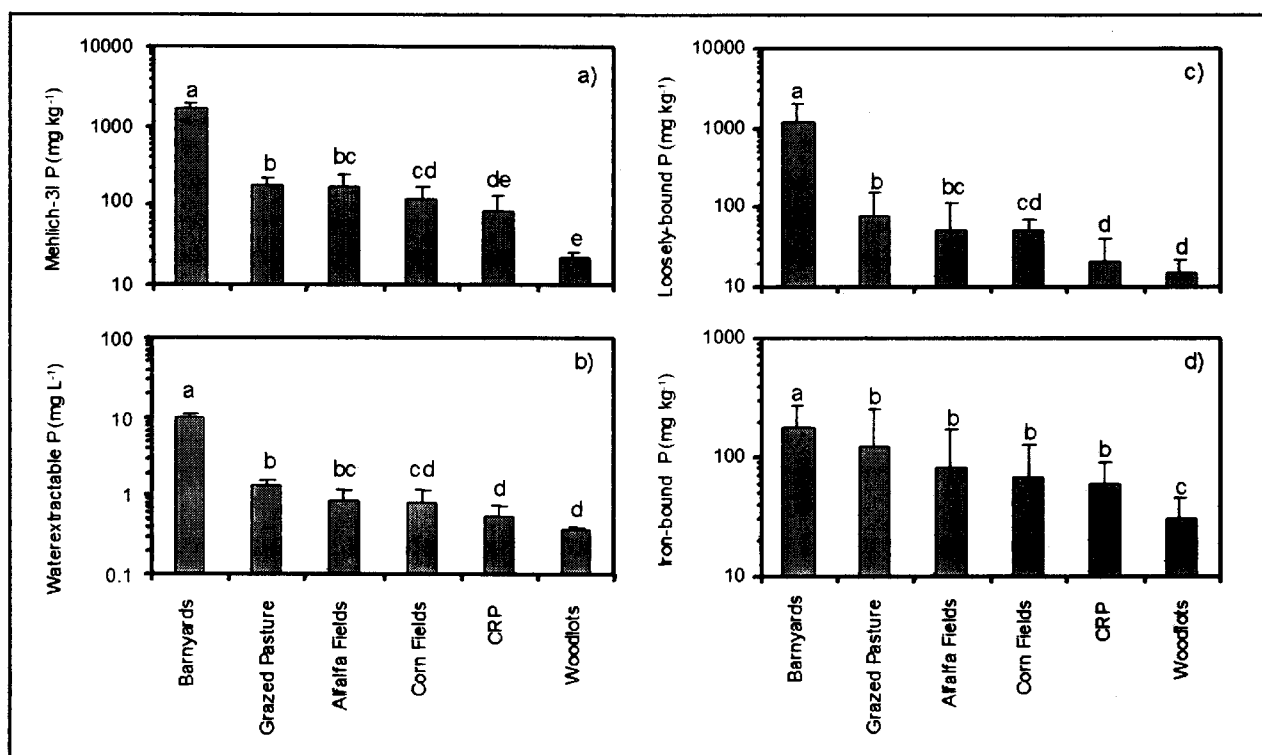
Figure 2. Mean (1 standard error = vertical line) concentrations of various soil phosphorus (P) species for soils from differing land uses in the upper Eau Galle River watershed. Soils that were not significantly different from each other based on ANOVA (SAS 1994) are marked with the same letter
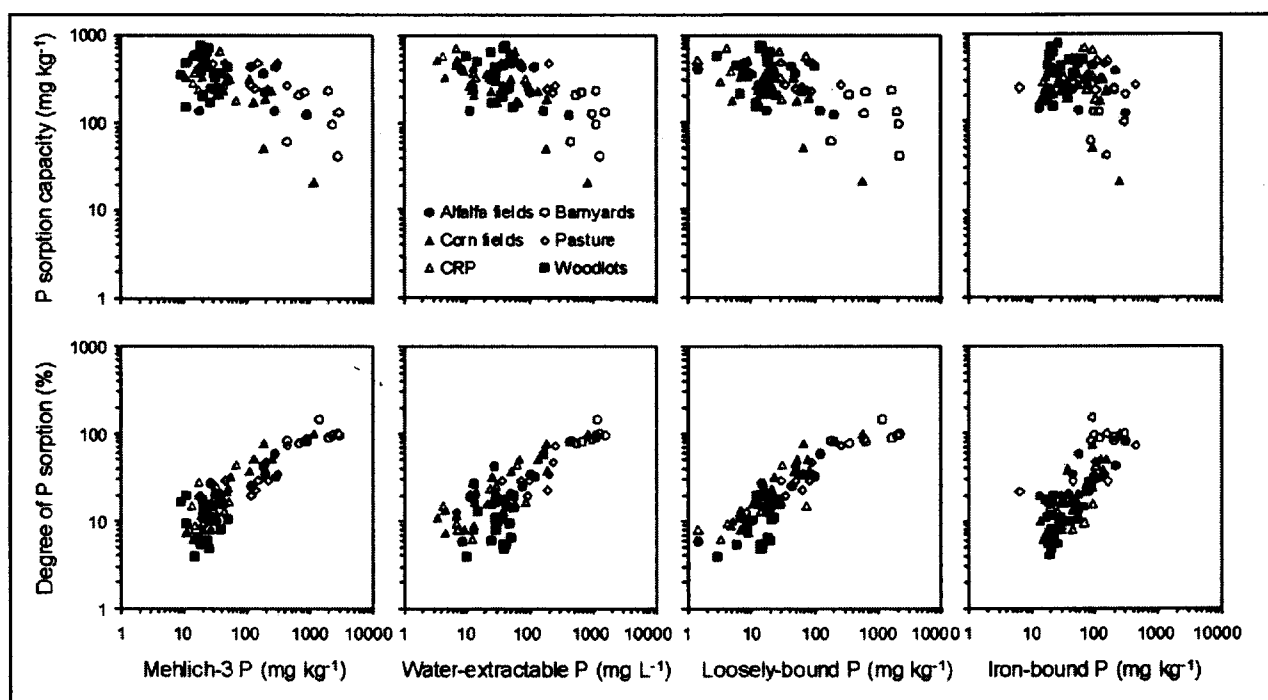
Figure 3. Relations between phosphorus (P) sorption capacity (upper panels) or the degree of P sorption (lower panels) and concentrations of soil Mehlich-3 P, water-extractable P, loosely bound P, and iron-bound P for soils from differing land-use practices at the upper Eau Galle River watershed. All least squares regression coefficients (SAS 1994) were significant at the 5-percent level or less

**Table 2
Correlation Coefficients (SAS 1994) for Various Extractable Phosphorus (P) Forms in the Soil and the Phosphorus Sorption Capacity (PSC) and the Degree of Phosphorus Sorption (DPS)**

Phosphorus Form	Water-extractable P (mg kg^{-1})	Loosely Bound P (mg kg^{-1})	Iron-bound P (mg kg^{-1})	PSC (mg kg^{-1})	DPS (%)
Mehlich-3 P (mg kg^{-1})	0.90	0.93	0.68	-0.60	0.88
Water-extractable P (mg kg^{-1})		0.89	0.55	-0.60	0.79
Loosely bound P (mg kg^{-1})			0.64	-0.58	0.88
Iron-bound P (mg kg^{-1})				-0.30	0.77
PSC (mg kg^{-1})					-0.70
[1] All correlation coefficients were significant at the 5-percent level or less.					

These results support the hypotheses that agriculturally managed soils exhibited a trend of higher DPS and lower PSC than unmanaged soils. In particular, barnyard land-use practices had the highest mean DPS and lowest mean PSC, indicating that these soils were rich in P and capable of contributing substantial soluble P during periods of runoff. Incorporation of livestock manure with a

high P content into soils, and sorption onto particles, most likely resulted in the high DPS and low PSC relative to other soils in the watershed (Nair et al. 1998, Nair and Graetz 2002).

An important finding was the observation of significant logarithmic relationships and correlations between the PSC or DPS and extractable forms of P in the soil. Positive and inverse logarithmic relationships between the DSP and PSC, respectively, and concentrations of water-extractable P, loosely bound P, iron-bound P, or Mehlich-3 P suggested that binding sites were more saturated as concentrations of extractable P forms in the soil increased. Water-extractable P increased with increasing DPS, indicating greater runoff potential of soluble P at higher soil DPS levels (Fang et al. 2002).

Findings from this study imply that land-use practice plays an important role in soil phosphorus levels in this watershed and that agriculturally managed soils are more saturated with respect to P than unmanaged soils. This type of information may be used in conjunction with watershed hydrological analysis to identify those areas that are most sensitive to soluble P runoff and thus high-priority targets for management aimed at improving water quality conditions in this and other Corps of Engineers receiving waters. Soil PSC and DPS information can also be used to more accurately categorize soils as a function of land-use practice as required in many watershed modeling applications.

ACKNOWLEDGMENTS: The author gratefully acknowledges L. Pommier, ASI Corporation, for performing the soil P fractionations and P sorption capacity assays.

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